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LATE-GLACIAL AND POSTGLACIAL HISTORY OF
THE CHAMPLAIN VALLEY.

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ABSTRACT.

Precise levelling of the elevated shore features on both sides of the Champlain Valley shows clearly two stages of glacial Lake Vermont, while, later, the sea flooded the valley southward from the St. Lawrence estuary only as far as Whitehall, New York. Thus New England was never cut off as an island in the late-glacial sea. Parallelism of the three major water planes in the valley shows that there was a long period of stability which ended soon after the marine water invaded the valley. This period of stability during the life history of Lake Vermont corresponds to stability in the Great Lakes region during Algonquin time while the period of tilting initiated soon after the marine invasion corresponds to tilting in late Algonquin time. Isobases drawn across the area are in harmony with those already drawn for northeastern North America.

INTRODUCTION.

Lake Champlain, occupying the bottom of a preglacial trough between the Adirondack mountains of New York and the Green Mountains of Vermont, is a very long and narrow body of water, exceeding a width of ten miles, only in the latitude of Burlington, Vermont. The level of the lake is held at 95 feet above the sea by the threshold across which the Richelieu River carries the outlet waters north to the St. Lawrence. Southward there are two narrow passes into the Hudson Valley; one at the southern tip of Lake George (573 feet) and a much lower one several miles north of Fort Edward, New York (147 feet). North of Ticonderoga, the lake is bordered by clay lowlands, continuous with those of the St. Lawrence. These low rolling clay plains are much broader on the Vermont side of the valley and here they are interrupted by occasional hard rock hills rising out of them like islands out of the sea.

It has long been recognized that as the Pleistocene ice front receded north through the Champlain Valley, an open body of water grew northward with it, finally occupying most of the



valley. Whether such water was entirely or only for part of the time marine, what outlets there were for any bodies of fresh water, from which direction the marine invasion came, whether or not tilting of the region was occurring during the recession of the ice—these are some of the problems that have confronted physiographers working in the Champlain Valley.

ASSEMBLY AND INTERPRETATION OF DATA.

Conspicuous on the slopes above the shore features of the present lake are other similar features at varying altitudes which have been explained by all investigators as having developed on the shores of earlier, higher water bodies. The following uplifted features have been used in this study of the water levels once existing in the valley, and these are the features that are plotted on the profiles (Figs. 15 and 16) by separate symbols.

1. *Beaches*, wave-heaped ridges of sand and gravel, were used most often. These are found in greatest numbers on the less exposed western slope of the valley. The altitude of the crest of each beach was measured with a 14 in. Wye level, though the water surface was probably a few feet lower. In such measurement of beach crests, a variation of several feet in the maximum crest height of any particular beach seemed reasonable, since a vertical range of five to seven feet can easily be explained as a result of the work of a single storm. Extreme seasonal variations of water level are known at present to exceed ten feet. Possible temporary plugging of the earlier narrow outlet southward at Fort Ann by floating icebergs might explain a vertical range of as much as 25 or 30 feet. Thus it is not necessary to invoke a change of outlet, or permanent change of water level for every beach of a given vertical series. The northerly component of the wind which seems probable if the glacial anticyclone (17) were here still in effect during the waning stages of the ice sheet, is betrayed by the prevailingly southerly developed hooks on many series such as at Peru, New York.

2. *Wave-cut- and wave-built terraces*, though found occasionally on the New York side, are most numerous in Vermont. The waves did not beat long enough on the shore to erode the bedrock, and even the glacial till was barely modified into rude terraces with boulders strewn over their surfaces. Since the brow of such features varies in altitude, the base of each cliff

was measured, though it is recognized that the water stood a few feet lower.

Conditions favoring the formation of beaches and terraces vary so much that one cannot expect that they will be developed along the entire strand line, and gaps of several miles without shore markers are common (Profiles, Figs. 15 and 16). North and south of such gaps, and on the opposite side of the valley, however, abundant shore features have been located, thus substantiating the water levels. On the other hand, the interpretation of water levels with gaps of many miles without substantiating features north or south, or of planes drawn from a very few such features on one side of the valley or the other, must remain in question.

3. *Kame terraces*, composed of gravel and sand, often poorly assorted and mixed with till, with their surfaces pitted with kettles, were developed where drainage from the highlands coalesced with thaw water from the ice in the depression between ice lobe and valley wall. Flowing down-valley parallel to the edge of the ice sheet, these waters reassorted old morainic material into a more or less evenly graded stream bed, one side of which was a valley wall, the other the ice. Much additional glaciofluvial material was added by the melt water stream. When the ice melted, the in-valley portion of the stream bed slumped, resulting in long, spectacular benches which have sometimes been interpreted as wave-built terraces by earlier workers. These features do enable a minimum estimate for the height of standing water at a given spot and time to be made.

4. *Normal deltas*, built by streams flowing into the earlier standing water bodies in the Champlain Valley were used, but on the profiles (Figs. 15 and 16), a symbol had to be employed which could be expanded to show the variation in altitude of the relatively flat surface of the delta itself.

5. *Proglacial deltas* are valuable in that their ice-contact slopes reveal exact positions of the ice front at given times.

6. *Kettles* have been used in an attempt to state the maximum level of standing water in a valley. The argument is that had standing water rested in the valley to a height above the surface in which they are found, the holes must have been filled with detritus. Since ice may persist a great many hundreds, or even thousands of years beneath gravel and sand before melting, the presence of unfilled kettle holes gives no real clue as to the height of water in the valley.

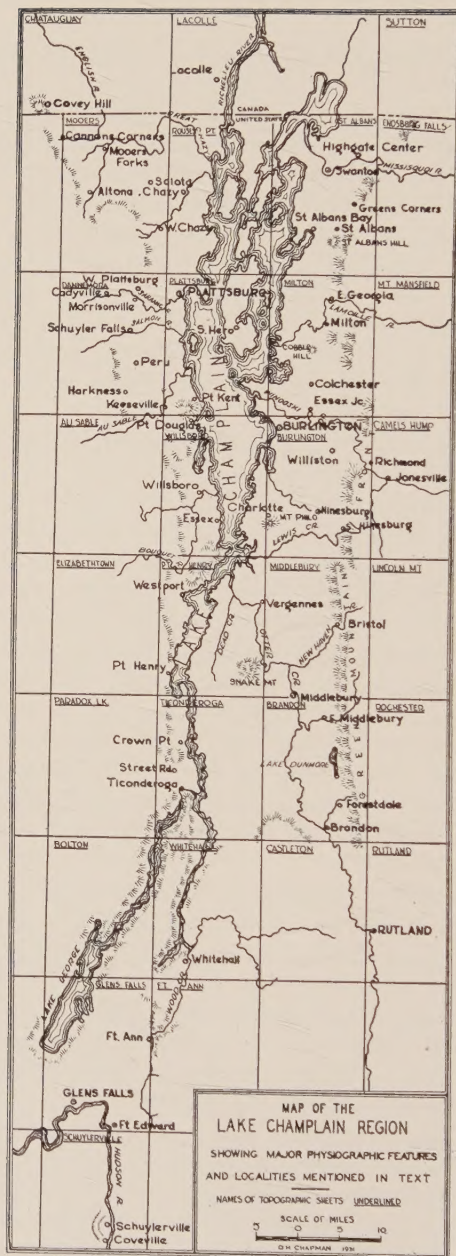


Fig. 1. Map of the Lake Champlain region showing the major physiographic features and localities mentioned in the text.

While early mention of the problems in the Champlain Valley was made by Emmons (6), C. H. Hitchcock, E. Hitchcock and others (16), and Upham (24), it was Baldwin (3) who first definitely recognized tilting in this valley. Although Peet (21) recognized two series of elevated shore features on the New York side of the valley, only Woodworth (25, 26), Fairchild (7, 8, 9, 10, 11, 12, 13) and Merwin (20) based their conclusions on extensive field studies. The method of plotting field data has been essentially the same in each study, including the present one. The altitude of each shore feature, beach, terrace, or delta, is plotted on a north-south profile of the valley. When all data are represented on such a profile, the features fall on inclined lines, which mark the uplifted and tilted surfaces of former bodies of water in the valley. The present study is the first to employ such water planes from both sides of the valley.

Woodworth (26) constructed three such tilted water planes, namely, Coveville and Fort Edward stages of Lake Vermont, and the Upper Marine Plane, which sloped toward the south at an approximate rate of 4.0 feet per mile. Fairchild believed the beaches were the result of wave action in a narrow strait extending from New York to Montreal. He drew but one plane, representing the maximum submergence, by connecting the highest beaches in each vertical series (13). He considered the lower beaches as waning stages of the marine invasion. His single water plane does not have a uniform tilt, but slopes more steeply near the Canadian boundary. Merwin's (20) work was limited to an area north of Middlebury, Vermont, where he recognized five water planes, the highest having the steepest tilt rate (5.9 feet per mile). The present interpretation more closely follows that of Woodworth than Fairchild, but there are certain important respects in which this interpretation differs from all previous ones.

SUMMARY OF LATE-GLACIAL EVENTS IN THE CHAMPLAIN VALLEY.

The Hudson-Champlain Valley during the wastage of the ice was occupied by a great ice lobe, fed from the north while the surrounding highlands were more or less free of ice. As the ice front receded a body of water expanded northward in the valley so that the nose of the lobe was continually bathed in water. Varved clay in the Champlain Valley is in itself proof that this water was fresh at least for part of the time.

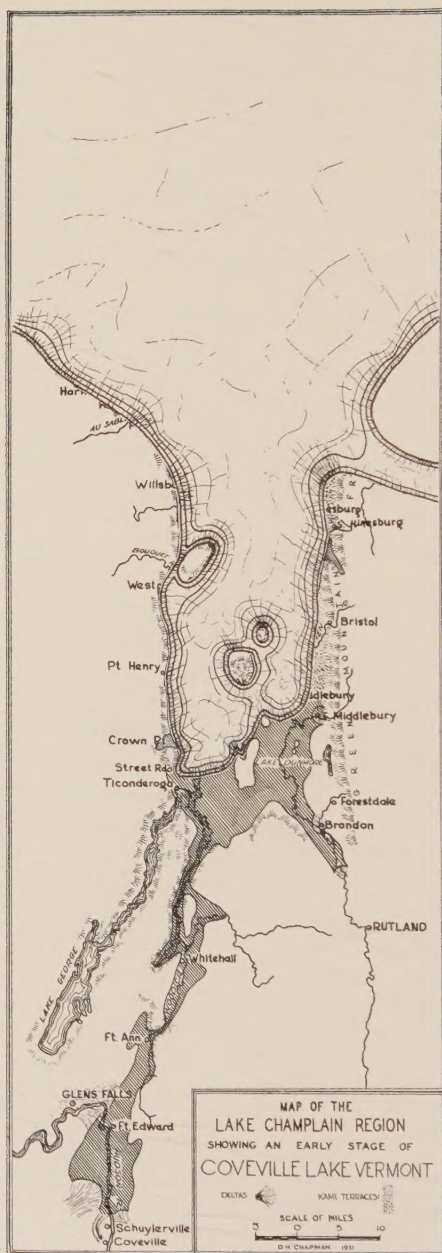


Fig. 2. Map of the Lake Champlain region showing an early phase of the Coveville stage of Lake Vermont.

Further proof of the existence of fresh water is described in this paper.

While the Champlain Valley itself was still entirely occupied by its great ice lobe, a body of water called "Lake Albany" (26, p. 175), lay against the ice front in the Hudson Valley. During the later stages of Lake Albany, when the ice front stood north of Schuylerville, gentle uplift of the region was taking place (5). Gradually great portions of the Hudson Valley south of Schuylerville emerged from beneath the waters of Lake Albany, until the falling water uncovered an obstacle to its further recession in a rock ledge at Coveville, three miles south of Schuylerville, which held back the water north of this point to form a new glacial lake: "Lake Vermont." During the recession of the ice in the Champlain Valley, Lake Vermont grew to great size and for a while continued to make use of the outlet at Coveville. Later, a lower stage of the same lake had a more northerly outlet.

LAKE VERMONT: COVEVILLE STAGE.

As may be seen from the profiles (Figs. 15 and 16), the elevated shore features in the Champlain Valley fall on a series of planes, rising to the north. The uppermost plane may be traced from near Ticonderoga, New York, and Brandon, Vermont, where the altitude is about 450 feet, northward to Plattsburg, New York, and Milton, Vermont, where the altitude is about 700 feet. This plane is believed to mark the earliest stage of Lake Vermont, and when projected southward, it leads directly to an abandoned channel of the Hudson River fifteen miles south of the city of Glens Falls, New York, and two miles west of Schuylerville. This channel, the "Coveville Outlet," has been described by Woodworth (26, pp. 196-7), and more recently discussed by Fairchild (10, pp. 10-11) and Stoller (23). At Coveville, where the southern end of this channel overhangs the Hudson River by more than a hundred feet, is a rock ledge which acted as the controlling threshold for the waters during the Coveville stage of Lake Vermont.

Early Phases of Coveville Stage. Whether or not Lake Vermont extended northward as far as the Champlain Valley at the time of its birth cannot be said, but surely before long the ice withdrew across the Hudson-Champlain divide near Fort Edward, and the lake history of the Champlain Valley began (Fig. 2).

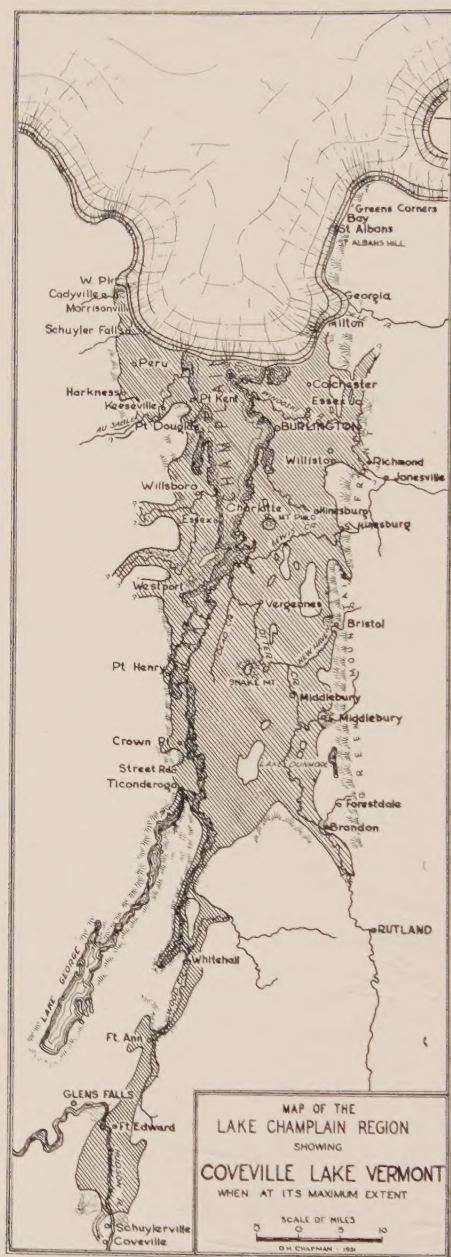


Fig. 3. Map of the Lake Champlain region showing the Coveville stage of Lake Vermont when at its maximum extent.

Gentle uplift and tilting, which was going on during the final stages of Lake Albany (5) possibly continued for a while as Lake Vermont grew northward into the Champlain Valley, for there are a few scattered deltas and at least one set of indistinct beaches above the true Coveville plane as far north as Bristol, Vermont. Woodworth (26, p. 193) described some such features in New York, which he correlated with an earlier Quaker Springs stage of Lake Vermont, and Barker (4) has more recently described similar features near Crown Point, New York. The best of these structures are plotted on the profiles (Figs. 15 and 16). On account of the meager development of these features in the Champlain Valley, the present writer inclines toward the view that many of these features at high levels were formed in local lakes or by water liberated from such local lakes escaping around mountain spurs, and he does not feel justified in recognizing the existence of a pre-Coveville stage of the glacial lake history of the Champlain Valley.

Main Coveville Stage (Fig. 3). Since the lake grew wider and wider as the ice front withdrew, the reach of the waves lengthened and hence the northern beaches and terraces are better developed. On the New York shore, the waves reworked the coarse material of the kame terrace at Sawyer Hill, three miles north of Ticonderoga, into a terrace (468 feet).¹ A still more perfectly developed terrace, whose surface is covered with assorted cobble, lies at 448 feet on the east slope of the same hill, running through the small cemetery west of the road.² This altitude places this feature on the Coveville plane. Coveville features in the vicinity of Crown Point village have been described by Barker (4). The beaches described by Woodworth (26, Plate 16), near Port Henry village, fall directly onto the plane as does the Elizabethtown, New York delta of the Bouquet River. The Coveville delta of the Little Ausable River, a mile west of Harkness, at an altitude of 660-665 feet (barometer), is pictured by Fairchild (13, Plate 14).

Two miles west of Peru Village is Clark School. Two Coveville beaches, with an altitude of 685 feet, lie across the first east-west road south of this building, where the road

¹ All altitudes given in this paper were precisely determined by Wye-level, unless otherwise indicated.

² As nearly as could be ascertained from Fairchild's description, this is the "shelf-bar" (13, p. 43).



Fig. 4. Map of the Lake Champlain region showing the Fort Ann stage of Lake Vermont when at its maximum extent.

turns southwest at a point one mile west of the schoolhouse; other Coveville features can be seen on the profile (Fig. 15). The delta that the Salmon River built into Lake Vermont during the Coveville stage may be observed at the foot of Terry and Burnt Hills near Peasleville. Two and one-half miles west-northwest of Schuyler Falls, just west of the four corners with an altitude of 677 feet, lies a splendidly developed beach (696 feet).

The Saranac River built a fine series of deltas into Lake Vermont and finally into the sea and the highest of these is conspicuous on the Dannemora topographic map one mile east of Cadyville village. Its level, gravelly surface at 729 feet (barometer) is interrupted by a series of shallow, partially filled kettle holes.

On the Vermont shore, the town of Brandon is built upon a flat sand plain deposited by the Neshobe River, during this stage of Lake Vermont (430 feet barometer). At South Hinesburg, there is a considerable accumulation of kame sand and gravel, formerly interpreted as a delta of Hollow Brook (20, p. 119; 8, p. 24). North of this "delta" for some distance there is an accumulation which Fairchild described as "storm bars" and other shore features. But the agreement in height of all of these features as well as the similar southward dipping beds of coarse gravel leads the writer to interpret them as a great kame terrace, formed at a time when the drainage escaped around the shoulder of Yantz Hill from Glacial Lake Winooski.

Mt. Philo, near the southwest corner of the Burlington quadrangle, stood as an island in Lake Vermont and received the full effect of wave attack. There does not appear to be good evidence of standing water against the slopes of this hill above 540 feet, where a terrace is cut into the till mantle at the second horseshoe curve in the road ascending to the summit (Fig. 11).

On the east slope of North Williston Hill is a set of beaches and the highest water level marker is at 641 feet, but the "sloping bar" (8, p. 25), and other "bar-like" features, as well as the "prominent cliff and terrace," are not wave formed.

The westward-facing slopes north of Burlington were searched without success for possible Coveville beaches. Cobble Hill, in the town of Milton, has no wave-formed features at the height of the Coveville water plane since the slopes at this critical height (670 feet) are entirely too steep. However, one



Fig. 5. Map of the Lake Champlain region showing the marine invasion when at its maximum extent.

and one-half miles southeast of Milton, there is a fine terrace the surface of which is strewn with cobble. Its continuity for over one-half mile and its breadth of over 100 feet make it one of the finest wave-cut features in Vermont. The altitude of the base of the cliff above this terrace is 666-668 feet and this altitude varies only a very few feet for its entire length. Careful search along the slopes of hills north of Milton brought to light no further features belonging on the Coveville water plane.

The shoreline of the Coveville stage of Lake Vermont cannot be traced northward into the St. Lawrence valley and from there to the sea, as might certainly be expected, were the features so far described marine, as Fairchild held. In fact, the Coveville features do not even reach the northern end of the Champlain Valley. The Cadyville delta, near Plattsburg, New York, and the Milton terrace in Vermont are the most northerly features on this plane. Apparently, when the ice front stood in the latitude of Plattsburg and Milton, this stage of Lake Vermont came to an abrupt end. This occurred when the Hudson gorge near Schuylerville was re-excavated and the water in the valley fell to a lower level. This level was determined by a new, more northerly threshold near Fort Ann, New York. Hence the following stage of Lake Vermont has been called the "Fort Ann stage." Although Lake Vermont during this time had essentially the same outlet as Woodworth's "Fort Edward" stage, different beaches have been correlated with this outlet and the lake therefore had a slightly different outline.

After the uplift, which may have been going on during the initial stages of Lake Vermont, had ceased, there was no differential uplift of the land until the ice had completely disappeared from the area and the marine waters had taken possession. The stability of the land during this long period is proved by the single set of shore features (i.e., not a series of wide vertical range) everywhere developed by the Coveville and Fort Ann stages of Lake Vermont. Examples of this are found in the narrow vertical range of the Upper Peru beaches in New York, the flat, rather than sloping tops of the deltas in New York and Vermont, and by the single, rather than multiple development of terraces at Mt. Philo, Cobble Hill, and Milton.

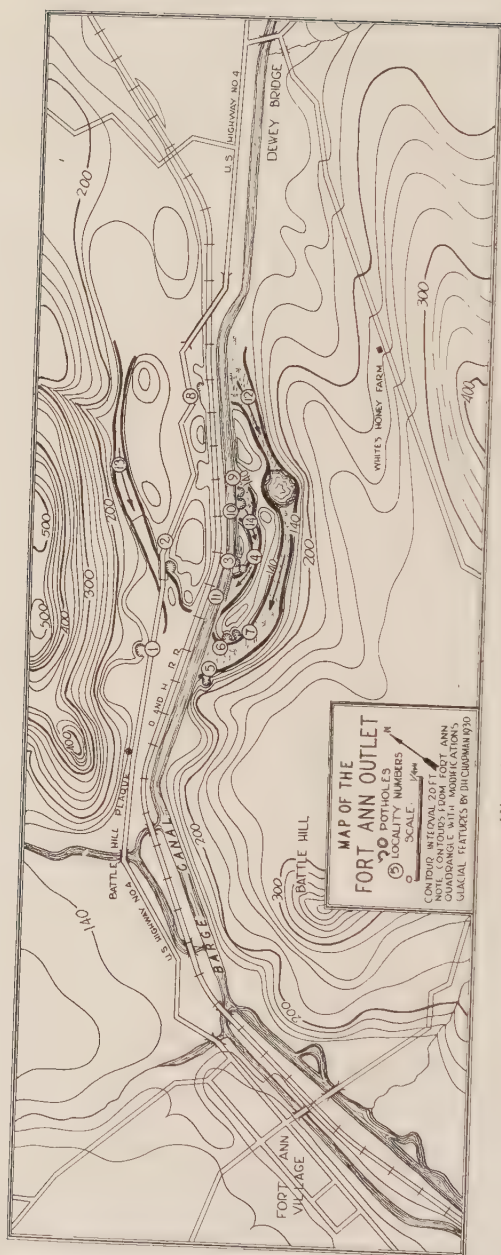


Fig. 6. Map of the Fort Ann outlet.

LAKE VERMONT: FORT ANN STAGE.

Below the shore features of the Coveville stage, another group, as shown on the profiles (Figs. 15 and 16), fall onto a plane, which, like the Coveville, rises northward. From south



Fig. 7. Pothole in the south wall of the Champlain barge canal near Fort Ann, New York. This hole apparently dissected when canal was blasted. (Locality No. 3, Fig. 6.)

of Ticonderoga, New York, and near Bristol, Vermont, where its altitude is about 390 feet, the plane rises to 749 feet at the International Boundary in New York and 591 feet in Vermont. When projected southward, this plane is directed toward the present-day divide between the Hudson and Champlain drainage, several miles north of Fort Edward, New York.

The Fort Ann Outlet. The present-day divide between the Lake Champlain Valley and that of the Hudson River lies three miles northeast of the city of Fort Edward, New York, in the center of a broad, flat valley, partially filled with clays and silts. Here there does not appear to be the slightest suggestion of current action such as one might expect to find at a threshold which controlled the waters for a glacial lake such as Lake Vermont. It is apparent that this divide itself was not the



Fig. 8. Circular pothole in glacial stream channel in Fort Ann gorge. Angular blocks result of blasting when Champlain canal was built. (Locality No. 4, Fig. 6.)

actual controlling point for the water in the Champlain Valley during this stage of lake history, as proposed by Woodworth. For the actual point of control, one must go to the gorge which lies northeast of the village of Fort Ann. Through this narrow gorge, the outlet waters for Lake Vermont during this stage rushed, and it is here that current action is to be found.

Various authors have mentioned this gorge (3, p. 178; 27, p. 674; 26, p. 198; 10, p. 10) but only Chadwick (5, p. 914) stated that the actual sill of Lake Vermont was here, nor did he describe any evidence of current action. There seems to be no question that this gorge acted as a stream channel, constricting the outlet waters of Lake Vermont during the Fort Ann stage and forcing them into great velocities.

The evidence for this statement, found by the present writer, rests in the presence of a great number of potholes, some quite large in size, in at least three river channels within the larger gorge which converge at the narrowest part of the valley; and in several outcrops of hard crystalline rock which have been fluted and polished by swift stream action. Fig. 6 is a map of this gorge and on it are located the major erosional features. There are many fine potholes, all within the limits of the three main tributary river channels, and all below 160 feet, the level at which water flowed through the valley. Figs. 7 and 8 illustrate two of the best potholes; their size and development may easily be noted. Each *roche moutonnée* is typically glaciated above the 160 foot limit as if not touched by direct current action since the retreat of the ice. Furthermore, had the potholes been of glacial origin, they would have been buried deeply beneath marine clay and silt, if the gorge from the first had been submerged beneath 200-300 feet of water, as Fairchild argued. Their freshness, and indeed their very presence, proves that their formation was the very last step in the moulding of the floor of this gorge.

Main Fort Ann Stage. The Fort Ann gorge outlasted the stay of the ice in the Champlain Valley, the ice wasting away to the north until the ice front probably stood not much farther south than the Canadian border (Fig. 4). Lake Vermont during the Fort Ann stage was not only longer and wider than it had been during the Coveville stage, but it also had a longer life, for some of the strongest features in the valley were formed during this period.

There is a fine terrace on the Street Road kame terrace, three miles north of Ticonderoga at 332 feet, which fits well onto the Fort Ann water plane, and there are other features in the Crown Point embayment which fall near this plane (4). The valley of the North Branch of the Bouquet River contains two tributary deltas built into Lake Vermont during this stage; one near Bouquet village and another one and a half miles north of the village of Reber. The Port Douglas beach ridge (26, p. 168-169) does not constitute an entirely satisfactory summit determination because the summit of the hill is so nearly on the water plane and the hill itself is much too high to be completely waveheaped.

One of the best series of raised beaches in the Champlain Valley occurs on the hill slopes at the base of the Adirondack mountain front three miles west of Peru, New York, where



the slope was favorable for their maximum development. They were mentioned briefly by Fairchild (13, p. 47), and were taken as a type example for special study by the present author because of their unusual strength and continuity. Nowhere else in the Champlain Valley did it seem practicable to ascertain the actual tilt of a single continuous beach. Fig. 9 presents the result of a precise level survey of this group of beaches. In addition to traverses made up the slope of the hill in five



Fig. 10. Fort Ann beach two miles northwest of Schuyler Falls, New York, showing hook and swale behind ridge, on right. Looking south. Altitude, 588 feet.

places, a longitudinal traverse of the 561-575 foot beach was completed. From this study the slope was determined to be 5.6 feet per mile, which checks very closely with the five feet per mile tilt rate of the Fort Ann water plane as drawn on the profile (Fig. 15).

Two miles northwest of Schuyler Falls is another excellent series of beaches (Fig. 10), the highest of which lies at 596 feet (barometer) or about 20 feet too low for the Fort Ann plane as drawn. This may represent a true sag in the water plane occurring when uplift took place. Another equally strong beach lies a mile and a quarter west of Beckwith school (600 feet). Two miles southwest of Morrisonville occurs another well developed series of beaches, reaching up to the Fort Ann water plane. The Saranac River during this stage built a

wide delta of sand, conspicuous on the Dannemora topographic map, northwest of Morrisonville at 630 feet (barometer), and its abrupt foreslope may be observed clearly from the highway on the east.

A morainic spur two miles north of West Plattsburg carries some of the most conspicuous beach ridges in this region (25, pp. 35-36; 13, p. 50). As the summit of this ridge lies at the altitude of the Fort Ann water plane (highest beach 645 feet, barometer), this series does not constitute an entirely satisfactory summit determination, but no higher beaches are found on the slopes west of here.

Three-quarters of a mile southwest of the three corners at West Beekmantown is another morainic ridge. Close examination of this hill showed that the summit is covered with a mantle of till, entirely unmodified by any wave action, and a rude terrace at 650 feet is the highest feature on the hill that can be considered as wave-formed. Though Woodworth mapped the upper portion of this hill as moraine (25, p. 34), Fairchild (13, p. 51) described and mapped wave action to its summit (700 feet).

At Shelter's Corners, two miles north-northwest of West Beekmantown, beaches may be observed on the eastward sloping hill up to, but not above, 665 feet, which is exactly on the Fort Ann plane. Above this, there are many short, discontinuous kame ridges, which have little significance as water level markers.

North of Shelter's Corners, on the Mooers quadrangle, there are numerous shore features which fall onto the Fort Ann plane (Profile, Fig. 15). Since these features have nearly all been described by Woodworth (25), they need not be discussed in detail here, but they are plotted on the profile (Fig. 15). The northernmost feature yet to be correlated with the Fort Ann stage is a beach at the three corners two and a half miles north of Cannon's Corners and a mile south of the International Boundary (749 feet). Woodworth considered all these features to belong to the Coveville stage, rather than to his Fort Edward (Fort Ann) stage, and he correlated with these features in the Mooers area certain other shore features on the Dannemora quadrangle, which unquestionably do belong to the Coveville stage of Lake Vermont. Thus in drawing such a plane with a low angle of tilt, Woodworth correlated definite Coveville features south of Cadyville with features north of that point that are in all probability Fort Ann. That he had

difficulty in explaining the height of the Cadyville delta (much too high for his Coveville plane (26, p. 160, 171), and that all the Dannemora features fail to reach his Coveville plane as drawn with a low angle of tilt, makes the present interpretation the more logical, for with the steeper tilt rate as drawn by the present author, the Dannemora features, including the Cadyville delta, fall on the Coveville plane.



Fig. 11. Mount Philo, south of Burlington, Vermont, looking east, showing Coveville (C) and Fort Ann (FA) wave-cut terraces. Altitude of Coveville terrace, 540 feet; Fort Ann terrace, 431 feet.

The northeastern corner of the Adirondack highlands is Covey Hill, less than a mile north of the International Boundary, in Quebec. One investigator (13, p. 55) described wave-cut "cliffs" and terraces up to 740 feet, but these terraces are very rude and all other writers (14, p. 120; 26, p. 162), including the present one, regard these terraces as marks of marginal ice streams.

During the last phases of the Coveville stage of Lake Vermont discharge of waters from the Lake Ontario basin took place through Covey Gulf (13, 26) and along the eastern flank of the Adirondacks. Much kamic material was strewn by these waters during this time as far south as Peru, New York. Later, as the ice withdrew from the northern flank of Covey Hill, the water from Lake Iroquois debouched around Covey

Hill into Lake Fort Ann, and it was at this time that the terraces on Covey Hill were shaped.

In Vermont, Snake Mountain, west of Middlebury, is one of the largest of the islands rising through the Champlain clays. A terrace on the west slope of this mountain at 386 feet falls on the Fort Ann plane but the feature lacks continuity. Other near-by terraces are definitely not wave cut. There are sandy beaches on the northwest flank of Buck Mountain, two and a half miles south of Vergennes (390 feet, barometer). On Mt. Philo, 13 miles south of Burlington, is one of the best developed and most characteristic features in the region. The lower and more prominent wave-cut terrace falls exactly on the Fort Ann water plane (Fig. 11. 431 feet).

The Winooski River deposited vast quantities of sand and fine gravel into Lake Vermont during this stage but the delta is too flat and broad to have a typical foreslope, the surface of the delta merging imperceptibly into the clay lake bottom. This may be the result of the fine grain-size of the material of which the delta is composed, the shallow depth of the lake, and the flatness of lake bottom. Similar deltas, without appreciable "brows," were sometimes built into the shallow glacial lakes in the Great Lakes basins, such as the delta of the Huron River, near Ypsilanti, Michigan (22). The surface of the Winooski delta rises to an altitude of a little over 500 feet at its apex near Williston, while the surface spreads north-westward as far as North Williston, Saxon Hill and Essex Center.

Cobble Hill, three miles south of Milton, carries one of the most conspicuous features in the entire valley. An outstanding terrace, or "collar," runs almost completely around the hill at an altitude of 527 feet. This shelf is fully 20 feet broad on the eastern slope and is visible for miles (Fig. 12).

A fine wave-cut terrace occurs on the hill slopes east of Mallets Creek and a mile southeast of Milton village. It can be traced with only minor interruptions for almost a mile along the face of the hill. The surface of the terrace (537 feet) is strewn with cobbles, washed from the till by waves, and though not attacked, the bedrock has been exposed at the base of the cliff.

On St. Albans Hill, just south of St. Albans village, is another good, wave-cut terrace (8, Plate III), and its altitude (570 feet) places it directly on the Fort Ann plane. Its width is greater than 30 feet, and the tread widens northward into a

beach which hooks eastward around the north end of the hill. On Aldis Hill, within the village limits of St. Albans, is a terrace at 580 feet which is probably wave formed, though extensive postglacial weathering has modified it considerably.

A terrace on the hill east of the Green's Corners Station lies on the Fort Ann water plane at 591 feet. Fifty feet broad and more than a half-mile in length, the cliff above this terrace is better developed than most, and there is a suggestion of



Fig. 12. Cobble Hill, south of Milton, Vermont, looking northwest and showing wave-built terrace formed during Fort Ann stage of Lake Vermont. Altitude, 527 feet.

wave work on some of the bedrock. The terrace surface is gravelly and covered with cobbles.

From Green's Corners into Canada, the hills are composed of a rapidly weathering black slate, so that it is not surprising that features of wave origin are lacking on their slopes.

During the last few years of the Fort Ann stage of Lake Vermont, as pointed out above, the waters from Lake Iroquois escaped around Covey Hill into the Champlain Valley. For a short time thereafter, Lake Vermont must have been confluent with Lake Frontenac around Covey Hill, but this condition could not have lasted long.

When the ice front had retreated to some point north of the Canadian border (2, p. 137), the waters of Lake Vermont began to soak through the low marginal portions of the ice

SIX MAJOR STAGES IN DEVELOPMENT OF LAKE CHAMPLAIN REGION

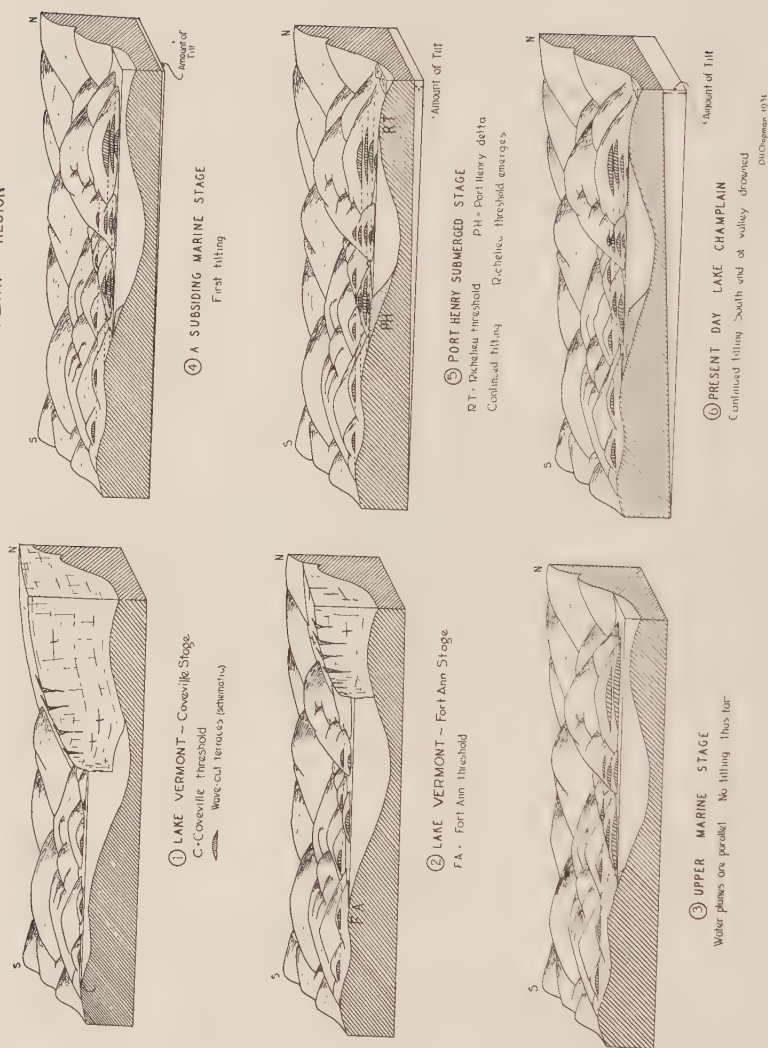


Fig. 13. Block diagrams showing the six major stages in the development of the Lake Champlain region.

lobe into the marine waters which were simultaneously creeping up the St. Lawrence valley as the ice evacuated that section. That the water from Lake Vermont did not find an outlet marginal to the ice along the Green Mountain front north of St. Albans is indicated by the absence of marginal channels which careful search failed to disclose. It is believed that the escape of Lake Vermont waters was almost wholly over, through and under rotting ice masses which represented what was left of the Lake Champlain lobe. Lack of evidence of standing water above the marine limit (475 feet) in the Missisquoi valley makes this hypothesis even more plausible. Antevs has suggested (1, p. 66) that a part of the ice sheet over southern Quebec and Gaspé was isolated from the main ice mass to the northwest and that the marine waters gained entrance between these masses.

That the water in the Champlain Valley stood at successively lower and lower positions during the escape of Lake Vermont, is indicated by the great series of beaches at and *below* (but not above) the Fort Ann limit in northern New York. (Fig. 15.) Undoubtedly many of these features were formed suddenly during some unusually violent storm, and hence each beach need not represent a halt in the lowering waters. There is a marked difference discovered in comparing the transition between Coveville and Fort Ann with that between Fort Ann and the marine invasion, for in the former case few beaches are found, while in the latter the transition is well marked. The former probably took place suddenly; the latter represents a longer period of time.

MARINE INVASION OF THE CHAMPLAIN VALLEY.

After the ice withdrew from the limits of the area, sea level waters flooded the valley (Fig. 5), to a relatively shallow depth. The Champlain estuary was a part of the larger St. Lawrence estuary, but it probably did not reach as far south as Whitehall, and certainly no farther. For if a water plane is drawn through the highest marine beaches, it plunges under the surface of the present-day Lake Champlain seventeen miles south of Ticonderoga, and intersects the floor of the lake two miles north of Whitehall. Hence, marine waters never could have invaded the Champlain Valley from the south, and sea level waters never could have cut New England off as an island by invading the Hudson-Champlain lowland from New York to Montreal in

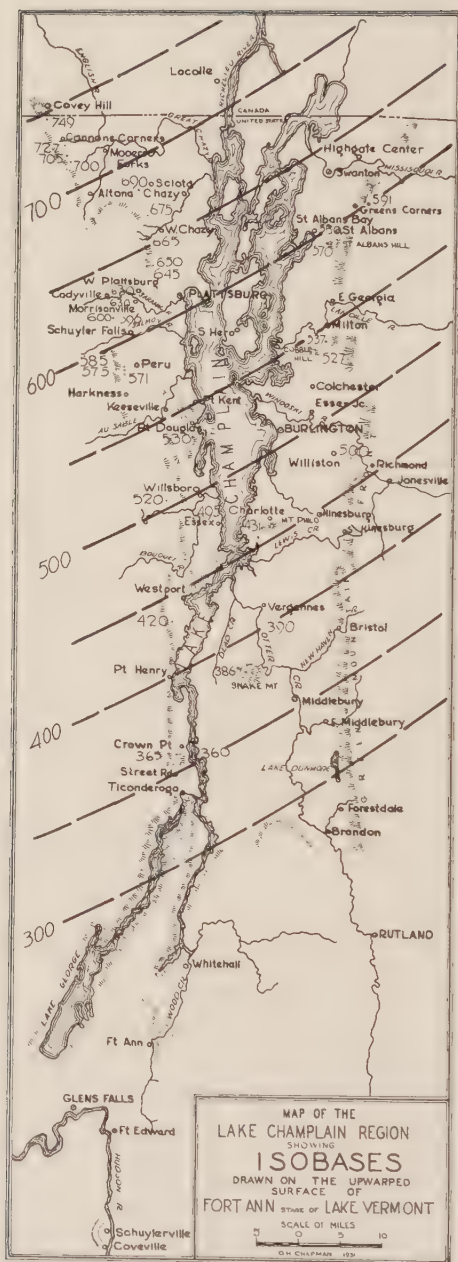


Fig. 14. Map of the Lake Champlain region showing isobases drawn on the upwarped surface of the Fort Ann stage of Lake Vermont.

one continuous estuary. Furthermore, a water plane drawn as the one described above is the highest possible marine water plane, for :

1. All marine shells so far found in the valley (21, 26) fall below the upper marine plane as here established.

2. The highest water plane which can be traced out of the Champlain Valley into the St. Lawrence and from there to the sea obviously represents the marine limit. A 440-450 foot terrace in St. Albans correlates with beaches in southern Quebec at Dunham, Cowansville, Granby, and Roxton (14, p. 120-121), which is the highest series of beaches which Goldthwait has traced along the St. Lawrence valley to the sea. Though the beaches at 525 feet at Covey Hill can be traced into the Ontario basin, this does not necessarily establish the marine origin of them, as it is conceivable that lakes in the Champlain and Ontario basins were confluent.

It is not surprising that no features are to be found on the Upper Marine plane near the southern end of the valley. The estuary was very narrow and tides probably caused a considerable fluctuation in water level (20, p. 120) and under these conditions shore features could not develop. A delta of Mullen Brook, four miles north of Port Henry, is the southernmost feature yet found on this plane in New York (240 feet, barometer). The flat-topped sand plain at the Westport village race track probably represents the material brought down by a small brook (270 feet, barometer). Many features are to be found on the Upper Marine plane north of Split Rock Mountain as shown on the profile (Fig. 15). An important one is the delta of the Saranac River (425 feet, barometer) at Morrisonville. On the Mooers quadrangle there are many features, all mapped by Woodworth (25) but almost all of these fall above his Upper Marine plane, since his plane was directed toward a limit of 450 feet at Covey Hill, rather than toward the true upper limit of 525 feet.

A clearly defined summit determination for the Upper Marine water plane was made on a series of beaches on the road running due west, one and a half miles west of West Chazy. The highest beach, just east of a deserted farm house, has an altitude of 467 feet directly on the water plane.

A beach near the International Boundary, north of the west branch of the English River, has an altitude of 539 feet, somewhat higher than the marine limit at Covey Hill a few miles farther north. This discrepancy is possibly more apparent than real, and may be due to the variation in the datum of the sur-

veys on either side of the International Boundary. The best summit determination in the Covey Hill region was obtained from a series of beaches on the road a quarter of a mile east of Covey Hill Post Office. Woodworth (25, p. 45) recorded the highest beach here at 450 feet, but this determination is much too low, for Goldthwait (14, p. 124) obtained a precise altitude of 523 feet on this uppermost beach. Fairchild (13, plate 8) described beaches west of Covey Hill which fall on this Upper Marine plane.

On the east side of the valley there are no good features south of the Burlington Quadrangle, so that the extent of the marine estuary in Vermont south of this point can only be approximately determined by projecting the Upper Marine plane from northern Vermont southward.

Southeast of Shelburne Falls, Vermont, a flat-topped, gravel covered terrace at 300 feet (barometer) may represent the delta of the La Platte River. The Winooski River built a broad, flat delta during this stage which is comparable to the one built during the Fort Ann stage. The surface of this marine delta rises gradually to an apex near Essex Junction at 340 feet. The ridge of red Cambrian quartzite, on which so much of the city of Burlington is built, may originally have stood out in the marine estuary as an island, but gradually the shallow bay east of it was filled with gravel and sand.

On the road leading northeast from Colchester Station, there is a gravel terrace at 355 feet which may represent the delta of a small brook during the Upper Marine stage, while a mile south of here a terrace on the westward sloping surface of a hill may be wave cut. Another feature nearby is that which the Lamoille River built into the marine estuary. Its apex reaches 395 feet at East Georgia, whence its surface, little modified by subsequent erosion, stretches off to the west. Farther north, in the southern portion of the city of St. Albans, and two or three blocks southeast of the High School, lies a terrace now much modified by street construction (440 feet, barometer). The water level must have been somewhat higher than this, but there is no longer a cliff behind this terrace to measure. This altitude nevertheless, fits well onto the Marine water plane.

SUBSIDING MARINE STAGES.

It has previously been stated that there was no tilting of the region from early Coveville time until the invasion of the marine waters, since the Coveville, Fort Ann, and Upper

Marine water planes are parallel. Soon after the entrance of the sea, however, the northern portion of the valley began to rise more rapidly than the southern, and this process continued for a long time, but was intermittent in character. (Fig. 13.) Heretofore, the story of the subsiding phases of the marine invasion in the Champlain Valley has not been attempted because of the number and confusion of beaches below the Upper Marine limit in northern New York. Not every beach below the Upper Marine limit represents a halt in the receding marine waters, for an extraordinarily strong storm might easily pile up a beach in a short time at a favorable locality, while nearby the effects of that particular storm might not be felt at all. Where a number of beach series seem to have a common upper limit, through which a tilted water plane may be drawn, and where deltas occur at corresponding altitudes, it is assumed that they were formed at the same time, indicating a halt in uplift for at least a short time. Such a relationship is found in at least five instances and while advancing the following correlation, the writer recognizes that it is only tentative. The following five stages are deduced from the evidence at hand. Four of the stages represented (Fig. 15) are to be found in New York, and at least three in Vermont (Fig. 16). The oldest (highest) have tilt angles which are greater, as might be expected.

1. *Beekmantown stage.* This stage is fairly strongly developed in New York north of Peru village, but no beaches in Vermont have been correlated with it. The principal features found on this water plane are: A delta of Arnold Brook, one and one-half miles northeast of Peru (320 feet, barometer); a series of beaches near Farrel Brook, near West Chazy (360-380 feet, barometer); a strong beach northwest of West Chazy (400 feet, barometer) which was mapped by Woodworth (25), and a sand and gravel plain south of Mooers Fork (425 feet, barometer).

2. *Port Kent stage.* This stage is much more strongly developed than the Beekmantown, and the upper limits are better defined. The southernmost feature is found as far south as Port Henry, where there is a terrace at 150 feet, near the railroad station (26, Plate 16). In regular order northward, principal features on this plane are: A delta of the Ausable River near Port Kent village (240-250 feet, barometer); an excellently developed series of beaches just west of the city limits of Plattsburg (highest beach 310 feet, barometer), ending in a splendid series of hooks just north of the Morrisonville Pike; a beach one and one-half miles south of West Chazy

FEATURES IN NEW YORK

(Figure 15)

Coveville Features

1. Terrace on Sawyer Hill, 468'
2. Terrace on Sawyer Hill, 448'
3. Sugar Hill terrace, 450'
4. Crown Point Center delta, 480'
5. Buck Mt. boulder pavement, 520'
6. Breed's Hill terrace, 520'
7. Russell Street Rd. terrace, 520'
8. Bulwagga Mt. beach, 460'
9. Port Henry beach, 500'
10. Port Henry beach, 510'
11. Elizabethtown delta, 600'
12. Harkness delta, 600'
13. Peru beaches, 685', 697'
14. Salmon R. delta, 690'
15. Schuyler Falls beach, 696'
16. Cadyville delta, 729'

Fort Ann Features

17. Terrace on Sawyer Hill (Street Road) 332'
18. Sugar Hill beach, 360'
19. Beach, 360'
20. Bouquet village delta, 490'
21. Reber village delta, 520'
22. Port Douglas beaches, 530'
23. Peru beaches, 530-590'
24. Schuyler Falls beach, 596'
25. Beckwith School beach, 600'
26. Morrisonville beaches, 630'
27. Morrisonville delta, 630'
28. W. Beekmantown beaches, 645'
29. W. Beekmantown terrace, 650'
30. Shelter's Corners beaches, 665'
31. Cobblestone Hill beaches, 675'
32. Pine Ridge beach, 680'
33. Deer Brook delta, 700'
34. Deer Pond beaches, 705'
35. Cannon's Corners beaches, 727'
36. Cannon's Corners Road beach, 749'

Upper Marine Features

37. Mullen Brook delta, 240'
38. Westport delta, 270'
39. Essex terrace, 300'
40. Essex beaches, 305'
41. Port Douglas terrace, 350'
42. Port Douglas delta, 360'
43. Ausable terrace, 370'
44. Ausable delta, 380'

45. Schuyler Falls delta, 400'
46. Schuyler Falls beaches, 398'
47. Schuyler Falls terrace, 405'
48. Morrisonville delta, 425'
49. W. Beekmantown beaches, 430'
50. W. Beekmantown beaches, 452'
51. W. Chazy beaches, 467'
52. Sciota beaches, 486'
53. Wood Falls beach, 500'
54. North Branch delta, 515'
55. Cannon's Corners beaches, 530'
56. English River beaches, 539'
57. Covey Hill beaches, 523'
58. Mt. Royal beach, 574'

Beekmantown Features

59. Arnold Brook delta, 320'
60. W. Beekmantown beaches, 360'
61. Farrel Brook beaches, 380'
62. W. Chazy beach, 400'
63. Mooers Forks delta, 425'

Port Kent Features

64. Port Henry terrace, 150'
65. Mullen Brook delta, 160'
66. Port Kent delta, 250'
67. Plattsburg beaches, 310'
68. W. Chazy beach, 320'
69. Covey Hill beaches, 350'

Burlington Features

70. Mooers Forks delta, 300'
71. Hemmingford beach, 280'

Plattsburg Features

72. Little Ausable delta, 150'
73. Saranac delta, 170'
74. Chazy beaches, 180'
75. Sherrington beach, 220'

Port Henry Features

76. Port Henry, submerged delta, 50'
77. Valcour Is., submerged terrace, 82'

Uncorrelated Features

78. Miranda beach, 155'
79. Clarenceville Beach, 150'
80. Hecks Corners beach, 160'
81. Phillipsburg beach, 130'
82. Venice beach, 130'

FEATURES IN VERMONT

(Figure 16)

Coveville Features

1. Forestdale delta, 600'
2. Bristol delta, 570'
3. Brandon delta, 430'
4. E. Middlebury delta, 480'
5. Bristol delta, 520'
6. Mt. Philo terrace, 540'
7. N. Williston Hill beaches, 641'
8. Milton terrace, 667'

Fort Ann Features

9. Snake Mt. terrace, 386'
10. Buck Mt. beaches, 390'
11. Mt. Philo terrace, 431'
12. Winooski delta, 500'
13. Cobble Hill terrace, 527'
14. Milton terrace, 537'
15. St. Albans Hill terrace, 570'
16. Aldis Hill terrace, 580'
17. Green's Corners terrace, 591'

Upper Marine Features

18. Shelburne Falls delta, 300'
19. Winooski delta, 340'
20. Colchester Station terrace, 385'
21. Colchester Station delta, 355'
22. Milton delta, 360'
23. Milton delta, 380'
24. E. Georgia delta, 395'
25. St. Albans terrace, 440'
26. Dunham beach, 509'

27. Cowansville beach, 519'
28. Granby beaches, 516', 560'
29. Roxton beach, 552'

Port Kent Features

30. Burlington delta, 225'
31. W. Milton delta, 260'
32. Highgate Creek delta, 320'
33. Adamsville beach, 390'

Burlington Features

34. Burlington delta, 160'
35. Starr Farm beaches, 165'
36. Bayside beach, 169'
37. Porter Point beach, 160'
38. Lamaille delta, 170'
39. St. Albans Hill terrace, 185'

Plattsburg Features

40. Sawyer's Bay terrace, 120'
41. St. Albans terrace, 140'
42. Swanton Junction beaches, 159'
43. Swanton Village beaches, 157'
44. Phillipsburg beach, 130'
45. St. Sabin beach, 200'
46. Abbottsford beach, 215'
47. Montreal beach, 225'

Port Henry Features

48. Port Henry, submerged delta, 50'

(320 feet, barometer), showing great continuity, and a series of beaches (340-350 feet) on the north slope of Covey Hill. In Vermont, scraps of a delta at Burlington (225 feet, barometer), a scrap of the Lamoille delta south of West Milton (260 feet, barometer), and the broad delta of the Missisquoi in the vicinity of Highgate Center (320 feet, barometer) are the major features belonging to this stage.

3. *Burlington stage.* In New York proper this stage is not easily recognized, but a beach at Hemmingford, Province of Quebec (280 feet, barometer), and a delta of the Great Chazy at Mooers Forks (300 feet, barometer) have tentatively been correlated with this stage.

In Vermont, the Winooski delta of this stage is found on both sides of the present mouth of the stream at an altitude not much above lake level. More definite water level markers are available nearby in a series of beaches crossing the road leading to Starr Farm, two or three miles northwest of the city of Burlington. These beaches, the highest of which has an altitude of 163-165 feet (and a single beach above at 172), though not extremely strong, are sandy, have great continuity and a horizontal crest line. Similar beaches are found a few miles farther north, near Porter Point. The Lamoille delta (150-170 feet, barometer) and a terrace at 185 feet, barometer, on the gentle hill slopes west of St. Albans hill probably also belong to this stage.

4. *Plattsburg stage.* The shoreline of this stage is submerged south of the latitude of Westport, New York. The principal features correlated are: A delta of the Little Ausable (150 feet, barometer) south of Plattsburg, the delta of the Saranac (170 feet, barometer) at Plattsburg Barracks and parade grounds, beaches east of the main highway north of Chazy village (180 feet, barometer), and a strong beach (220-225 feet, barometer) between Barrington and Sherrington, Province of Quebec. In Vermont on South Hero Island, a terrace (120 feet, barometer) overlooking Sawyers Bay, terraces east of St. Albans Bay on the mainland (140 feet, barometer), two strongly developed beaches two and a half miles southwest of Swanton Junction (150 feet, barometer), and a good series of beaches three miles southwest of Swanton village (157 feet, barometer), all seem to have been formed at this time.

A few beaches around the northern end of Lake Champlain in Canada have also been correlated with this stage, and are all plotted on the profile (Fig. 16). There are other beaches at a

lower altitude, also represented on the profile, which have so far not been correlated with any stage.

5. *Port Henry (submerged) stage.* Differential uplift brought the northern end of the valley out of water more rapidly than the southern. *Emergence* must have been taking place, nevertheless, throughout the *entire length* of the valley. Streams at the southern end cut down into the weak delta and lake bottom materials of earlier stages. But there finally came a time, as the land rose, when the Richelieu threshold in southern Quebec, just north of the International Boundary, began to act as a barrier for the sea waters. Once out of water, the Richelieu region barred the marine water from entering the valley, and at the same time held back a portion of the old estuary to form a new fresh water lake with outlet toward the north (Fig. 13). The level of the water in the valley stood constant for a long time just as the sea was being excluded for the last time. During this critical period, a large stream flowed north along a course marked today by the deepest part of the present lake between Whitehall and Port Henry, and cut a meandering channel well displayed on the Government Lake Charts. This stream reached standing water level five miles northeast of Port Henry and dropped its load to build the "Port Henry delta." Peet (21, pp. 466-8) mentioned this submerged river channel and delta, but made no attempt to correlate it with the history of the Champlain Valley. Contour lines drawn on the lake floor, and cross-sections of this feature show that it has a typical deltaic shape, with flat top and a fore-slope of but four degrees. This feature is not simply a pre-existing configuration of the lake bottom, for the steepest portion of the shore is opposite the flat, shallow, delta-like portion of the lake floor, while the deeper portions of the lake are opposite the low, flat, clay shores. The delta, then, was built into water at sea-level during a transition stage, beginning just before salt water was excluded for the last time, and ending just after a fresh water body was established. This stage may have lasted a long time, as would be indicated by the large bulk of material making up the supposed delta. Terraces south of Plattsburg (18) visible now only at times of extremely low water, may belong to this same phase of lowest level in the valley.

PRESENT-DAY LAKE CHAMPLAIN.

Further tilting of the land upward at the north caused overflooding of the Champlain waters toward the south end of the

valley (Fig. 13). Former deltas, such as the one near Port Henry, were submerged, and old river channels filled up with detrital material. The valleys near the south end of the lake were drowned. The Port Henry delta is under sixty feet of water; the Plattsburg terraces are under twenty to thirty feet; Otter Creek and other streams south of Middlebury have wide, swampy valleys and the mouths of all valleys are characteristically trumpet-shaped.

Whether tilting is going on at present is not known. It is interesting, however, that a tilt of but four-tenths of a foot per mile would be necessary to make the water of Lake Champlain once again flow south across the Fort Ann divide into the Hudson valley. This amount is one-half that which has taken place since the exclusion of marine waters, and but one-tenth of that which has taken place since the first invasion of the marine waters.

CONCLUSIONS.

The most important conclusions of the present work are that :

1. Marine waters invaded the Champlain Valley from the north during late-glacial time, but sea-level water never reached as far south as the Hudson valley and hence New England never was cut off as an island in a late-glacial sea.

2. Previous to the marine invasion, an ice-dammed lake, "Lake Vermont," existed in the valley, and two stages of the lake can be detected.

3. During the life history of Lake Vermont, from a time shortly after the beginning of the Coveville stage, up to and including the time when marine waters first entered from the north, the Champlain Valley was stable, as proved by the parallelism between the Coveville, Fort Ann and Upper Marine water planes.

4. The life history of Lake Vermont correlates with the stability noted by Leverett and Taylor (19) in the Great Lakes region during Algonquin time. If we place the period of stability in the Champlain Valley equal to Taylor's first period of stability during the Kirkfield (Fenelon Falls) stage of Lake Algonquin, then the tilting registered at Glens Falls is the last phase of the Post-Whittlesey Tilt, which, according to Taylor, immediately preceded the opening of the Kirkfield (Fenelon Falls) outlet. This is just at the time of the beginning of the life history of Lake Iroquois in the Ontario basin. Thus, *the life history of Lake Vermont correlates with the stability in the Great Lakes region during Algonquin time.* Stability continued even after Lake Iroquois escaped around Covey Hill, and Lake Frontenac was confluent

with the Fort Ann stage of Lake Vermont, which is what Taylor implies in his diagram (19, Plate XXI, p. 410).

5. The tilting of the Coveville, Fort Ann and Upper Marine planes was accomplished during the tilting of late Algonquin time (19) and Taylor's second period of stability may possibly be expressed in the long life of the submerged Port Henry delta.

6. *Amount and Direction of Tilt in the Champlain Region.* That the features of the New York shore lie at an altitude somewhat higher than features belonging to the same stage and at the same latitude on the Vermont side indicates that the direction of maximum tilt is not due north-south, but rather south-southeast and thus the isobases, when drawn on the tilted water planes of Lake Vermont, run from east-northeast to west-southwest. The trend of the isobases as drawn on the tilted surface of the Fort Ann stage of Lake Vermont (Fig. 14) are in agreement with those drawn by Taylor (19) in the Great Lakes region and by Goldthwait (15) in New England and the St. Lawrence valley. The apparent flattening of the marine plane north of the International Boundary (Figs. 15 and 16) is due to the fact that features in the St. Lawrence valley far east of the Champlain Valley are plotted. North of the boundary, then, the profile runs nearly parallel with the isobases, and the true amount of tilt does not appear.

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